INVESTIGATIONS ON EFFECT OF INCORPORATION OF PHOTOVOLTAIC SYSTEM WITH COMBINED CYCLE GAS TURBINEPLANT

Naimul Hasan[1] , B.B .Arora[2], J.N. Rai[3]

[1]*Department of Electrical Engineering, Jamia Millia Islamia .New Delhi*

[2]*Department of Mechanical Engineering, Delhi Technological University,Delhi, India*

[3] *Research Scholar, Dept. Of Elec. Engg, Jamia Miliia Islamia, N.Delhi*

ABSTRACT

India is witnessing a huge demand in power requirement. Economic development has led to development in Industries and demand for housing has increased. To meet this ever-rising power demand, efforts have been made to increase the efficiency at the generating end. One of such efforts is the CCGT plant in which the exhaust of Gas Turbine is used to run the Steam Turbine; hence giving an overall efficiency upto 60%. But, the recent trends in electrical engineering has been shifted to renewable forms of energy via solar, wind et,.keeping in mind the emphasis is on importance ofsustainable development. This paper is a preliminary study of how solar energy can be used through photovoltaic panels for the excitation of GT and auxiliary purposes in CCGT plant. The results of the same have been plotted and the future developments of this research have been discussed in detail.

Keywords: Solar, PV, CCGT, Power, Photovoltaic

I INTRODUCTION

In power systems, various methods are employed to overcome the ever-rising electricity demand. In India, most Power Plants are driven by fossil fuels. A Combined Cycle Gas Turbine Plant(Fig. 1)is one themeans so as to make the efficiency of a plant to reach the 60% mark.[1][4].

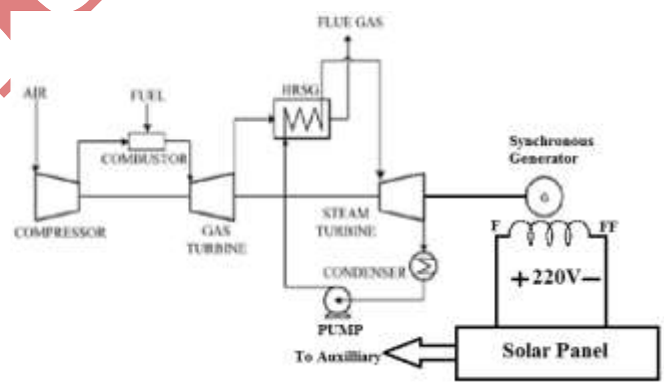

Fig 1. Combined Cycle Gas Turbine with Solar Panel

In a CCGT plant, the input temperature to a steam turbine is about 540°C and the exhaust can be maintained at the atmospheric pressure, due to design consideration the input temperature is limited and the efficiency of the about 45%. Theinput temperature of the gas turbine can be as high as 1100°C but the exhaust temperature can be lowered to about 550-650°C, the efficiency of a gas turbine is about 35%. It can be seen that to obtain higher efficiencies the exhaust of the gas turbine can used to drive the steam turbine giving efficiency up to 62%.The plant consists of a compressor, combustor, gas turbine, waste heat recovery boiler, steam turbine, and generator(s) associated with solar voltaic. [7][8]

Similarly, the emerging form of energy (Renewable Energy) is a socially and politically defined category of energy sources. Solar energy being one of them.Hence, we can employ solar panelswith the CCGT plant to make it less dependent on fossil fuels. The tariff for the consumers would also go down, since solar energy is at its peak in summer season, the time the electricity utilization is maximum in a year.

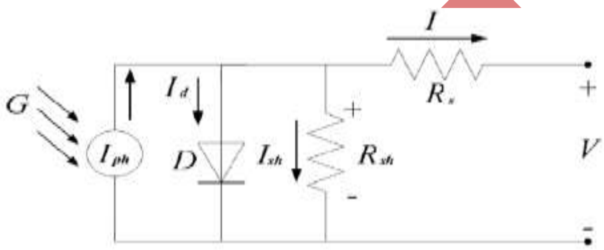

Fig 2. Equivalent Circuit of a PV cell

A simplest equivalent circuit(Fig. 2) of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the solar energy (photons) that hits on the solar cell (photocurrent I_{ph}). During darkness, the solar cell is not an active device; it works as a diode, i.e. a p-n junction. It produces neither a current nor a voltage. However, if it is allowed to connect to an external source (large voltage) it generates a current *Id*, called diode (D) current or dark current. [15]

Hence the combination of solar energy with CCGT plant could make a possible difference.

II THEORETICAL BACKGROUND

Equations which define the model of a CCGT Plant:The airflow (W) in the gas turbine is given as

$$W = W_a \frac{P_a}{P_{ao}} \frac{T_{io}}{T_i} \qquad (1)$$

Where Ti is ambient temperature and P_a denotes the atmospheric pressure.

$$\eta_{cc} = \eta_{gt} + \eta_{st}(1 - \eta_{gt}) \qquad (2)$$

The Where η_{cc} is the efficiency of the combined cycle, η_{gt} is the efficiency of Gas Turbine and η_{st} is the efficiency of Steam Turbine.thermal efficiency of the simple gas turbine cycle is given as [6]

$$\eta = \frac{(1 - \frac{1}{p_p})(a - p_p)}{\eta_c (k_1 - 1) - p_p + 1} \qquad (3)$$

Where, $a = \eta_c \eta_t k_1$ [10][11][12]Equations which define the model of a PV cell:

$$V_t = \frac{kT_{op}}{q} \qquad (4)$$

$$V_{oc} = V_t \ln\left(\frac{I_{ph}}{I_S}\right) \qquad (5)$$

$$I_d = \left[e^{\frac{(V+IR_s)}{(nV_tCN_s)}} - 1 \right] I_s N_p \qquad (6)$$

$$I_S = I_{rs}\left(\frac{T_{op}}{T_{ref}}\right)^3 e^{\left[\frac{qE_g}{nk}\left(\frac{1}{T_{op}}-\frac{1}{T_{ref}}\right)\right]} \qquad (7)$$

$$I_{rs} = \frac{I_{sc}}{\left[e^{\left(\frac{V_{oc}q}{kCT_{op}n}\right)} - 1 \right]} \qquad (8)$$

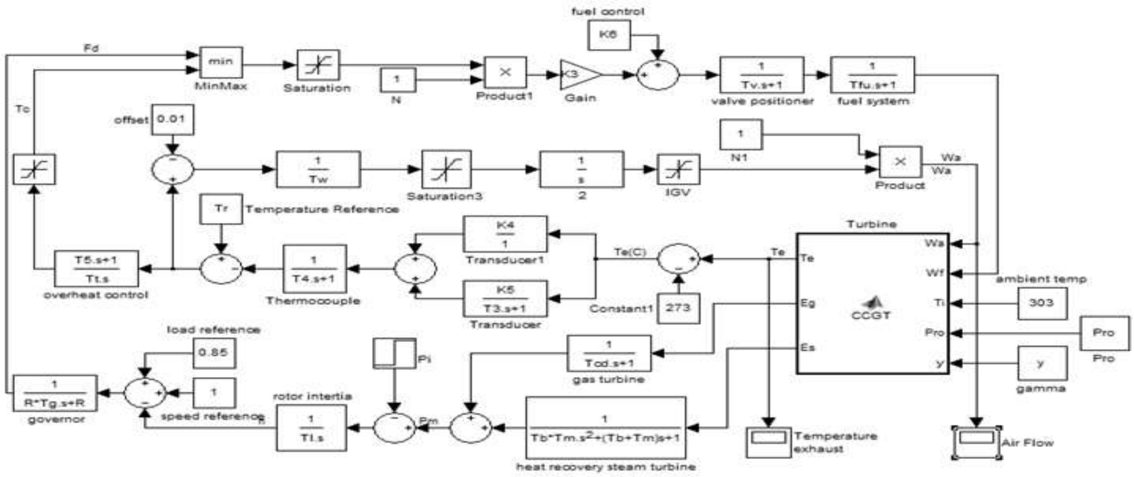

Fig 3. CCGT Simulink Model

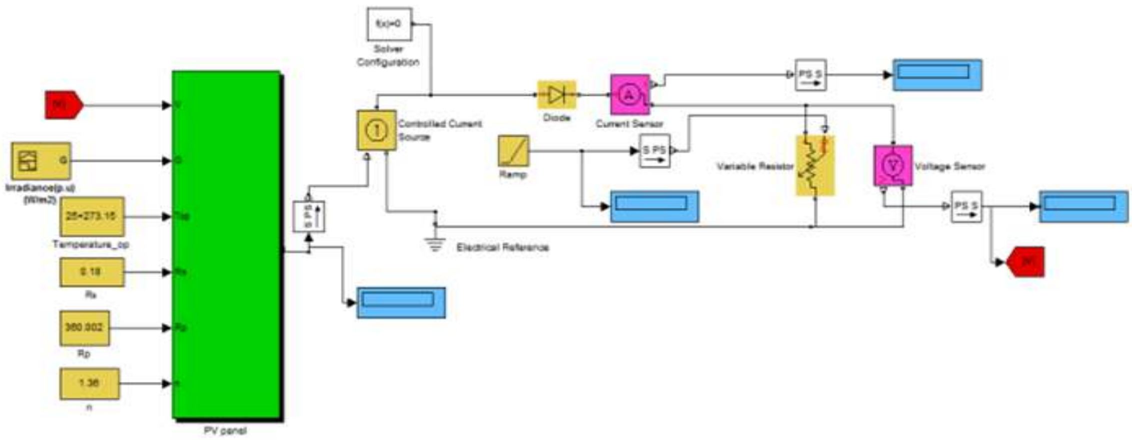

Fig 4. Simulink Model of Photovoltaic Panel

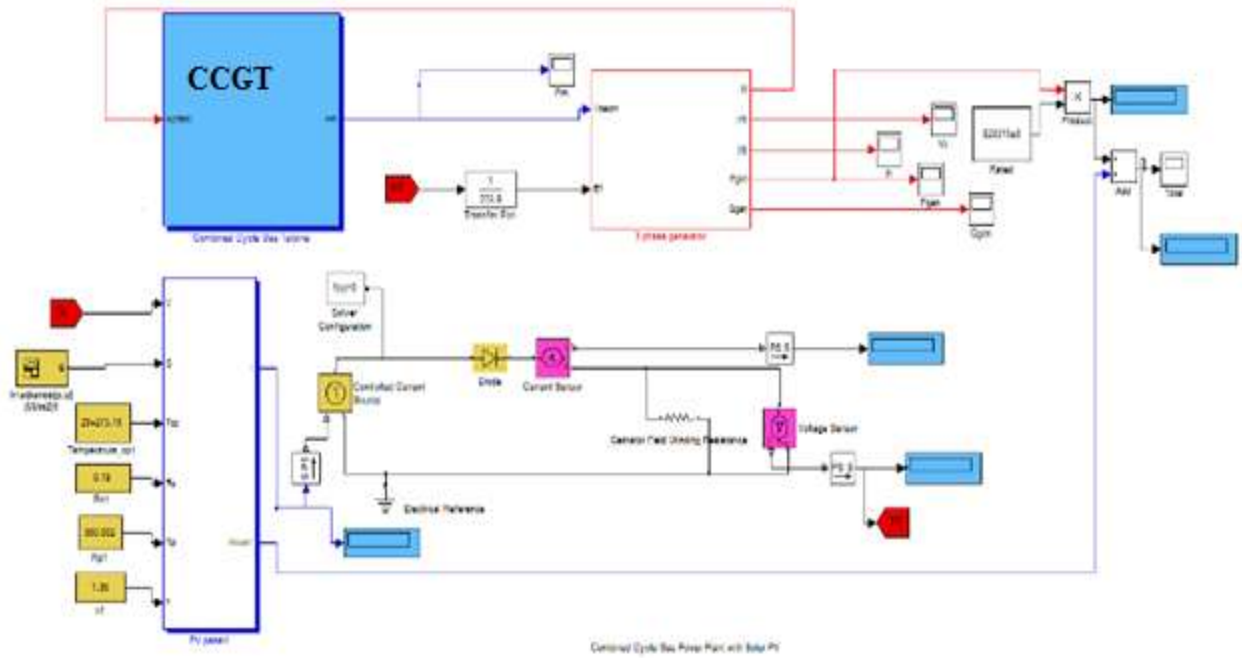

Fig 5. Simulink Model of Integrated Photovoltaic in CCGT

$$I_{sh} = \frac{V + IR_s}{R_p} \quad (9)$$

$$I_{ph} = G_k \left[I_{sc} + K_I (T_{op} - T_{ref}) \right] \quad (10)$$

$$I = I_{ph} N_p - I_d - I_{sh} \quad (11)$$

where, $G_k$is solar insolation in W/m^2,

$T_{ref}$is reference temperature(298 K),

$T_{op}$is operating temperature of cell,

$R_s$is series resistance,

$R_{sh}$is shunt resistance,

k is Boltzmann constant,K is temperature coefficient,

N is data points used,

n is diode emission factor,

$I_{ph}$is photon current & I_d is dark current,

I_{sh} is short circuit current at reference state.

III DESCRIPTION OF SIMULINK MODEL AND RESULTS

The CCGT model (J. N. Rai. et.al. 2013)consists of various blocksdescribing various parameters whose variations have already been studied in order to optimize the performance of combined cycle. There are blocks related with speed/load, temperature control, fuel control, air control and other blocks for gas turbine, waste heat

IJEEE

recovery boiler/steam turbine, rotor shaft, and temperature transducer. All the parameters used in the model are given in Table I& II. [2] [3][5]

A circuit based simulation model for a PV cell for estimating the IV characteristic (temperature and irradiance) and cell parameters (parasitic resistance and idealty factor)has been discussed. The simulation model is used for analysing the behaviour of PV Panel by varying various parameters of the cell in accordance with the given equations. Using a Shockley diode equationan accurate *simulink* PV panel model was developed.The model is based on the equivalent diagram of the solar panel described in the theoretical background. [12] [13] [14]

Further with above Simulink model the response of CCGT. has been investigated which shows the variation of current with respect to the timeFigure 6.

Figure. 7 shows the Variation of Generated Electrical Power. It depicts the variation is almost constant. The output is stable. It can also be seen that the generator output falls which is also controllable with reactive power control as shown in Figure.8.

Further the effect of varying input condition of CCGT as Variation of CCGT parameter i.e Exhaust Temperature of Gas Turbine (^{o}C), Air Flow (p.u.) and Fuel Flow (p.u) (Figure. 9) has been investigated.

Turbine Output (input of generator) is constant for a while (Figure 10). As the system is uncontrollable, the output falls which can be brought to the near to its rated value by controlling the CCGT parameters. The Field Excitation for synchronous generator is accompanied with solar voltaic which shows the positive impact on the performance. It can also be seen that now the start-up time is higher than the normal plant model (J. N. Rai et.al. 2013) with increased power output.

IV CONCLUSION

The parameters considered above cannot be varied simultaneously due to complexity of system. Some parameters are located and the other parameters will be the function of critical parameters in one way or the other. Interrelations amongst the various parameters are balanced by superimposing some constraints on the parameters.The level of benefits achieved as a result of system optimization has included the following:

- Increased output-3 to 5%
- Reduced fuel consumption-3 to 5%
- Reduced power consumption-3 to 5%

Both, the CCGT and PV panel models are combined. PV panel is used to give the excitation to the CCGT Plant Generator and also the remaining energy developed can be used for driving the auxiliaries in the Plant. Since the solar output is DC itself, the conversion losses from AC to DC as was the earlier case in CCGT plant have been taken care of. Start-up Time would be high as compared to Normal Combined Cycle Gas Power Plant.

This paper provides a path for further research work in future by integrating solar plant to increase the clean energy generation and to enhance the existing plant capacity in India.

IJEEE

Table 1 : System Parameters

Symbol	Description	Value
T_i	Compressor inlet temperature	$30\,^\circ C$
T_{do}	Compressor discharge temperature	$390\,^\circ C$
T_{fo}	Gas turbine inlet temperature	$1085\,^\circ C$
T_{eo}	Gas turbine exhaust temperature	$535\,^\circ C$
P_{ro}	Compressor pressure ratio	11.5
γ	Ratio of specific heat	1.4
η_c	Compressor efficiency	0.85
η_t	Turbine efficiency	0.85
R	Speed Regulation	0.04
T_t	Temperature control integration rate	0.469
$T_{c\,max}$	Temperature control upper limit	1.1
$T_{c\,min}$	Temperature control lower limit	0
$F_{d\,max}$	Fuel control upper limit	1.5
$F_{d\,min}$	Fuel control lower limit	0
T_v	Valve positioner time constant	0.05
T_{fu}	Fuel system time constant	0.4
T_w	Air control time constant	0.4669
T_{cd}	Compressor volume time constant	0.2
K_0	Gas turbine output coefficient	0.0033
K_1	Steam turbine output coefficient	0.00043
T_g	Governor time constant	0.05
K_4	Gain of radiation shield	0.8
K_5	Gain of radiation shield	0.2
T_3	Radiation shield time constant	15
T_4	Thermocouple time constant	2.5
T_5	Temperature control time constant	3.3
K_3	Ratio of fuel adjustment	0.77
K_6	Fuel valve lower limit	0.23
T_m	Tube metal heat capacitance time constant of waste heat recovery boiler	5
T_b	Boiler storage time constant of waste heat recovery boiler	20
T_i	Turbine rotor time constant	18.5

IJEEE

Table II. Parameters of Three-Phase Synchronous Machine

Symbol	Description	Value
Fr	Rated Frequency	50
Poles	Number of poles of the generator	4
Pf	Rated Power Factor	0.9
V_R	Rated Voltage	11Kv
Pr	Rated output Power in Watt	82.831Mw
Rs	Synchronous Resistance	0.0048
X_d	Direct-Axis Reactance	1.790
Xq	Quadrature-Axis Reactance	1.660
X_{ls}	Leakage Reactance	0.215
H	Interia Constant	3.77
K_A	Gain Constant	50
T_A	Amplifier Time Constant	.06
V_{Rmax}	Maximum Voltage	1
V_{Rmin}	Minimum Voltage	-1
T_E	Exciter Time Constant	0.052
K_E	Exciter Gain	-0.0465
T_F	Field Time Constant	1.0
K_F	Field Gain	0.0832

IJEEE

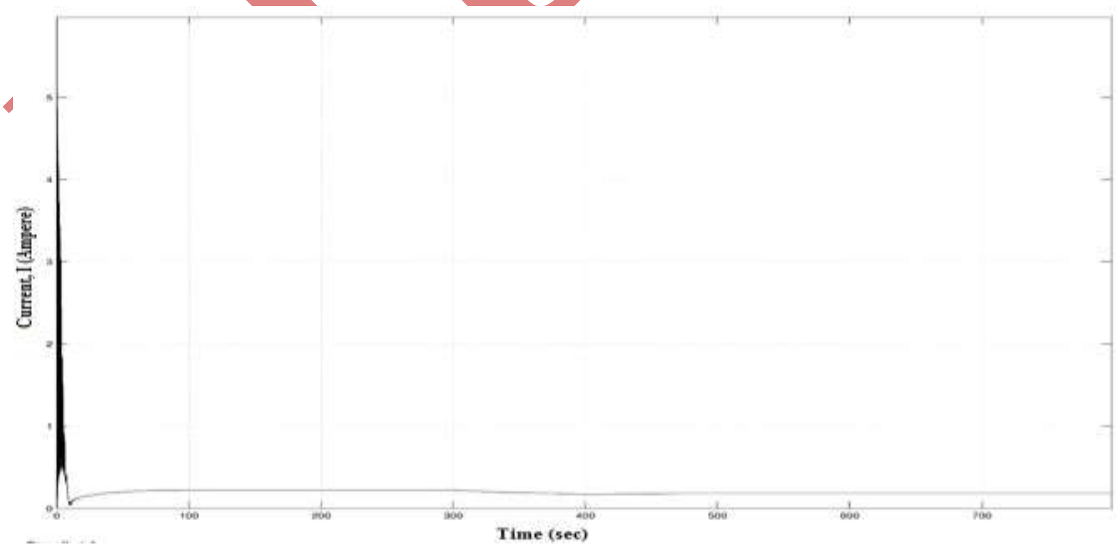

Fig 6. Variation of Current with Time

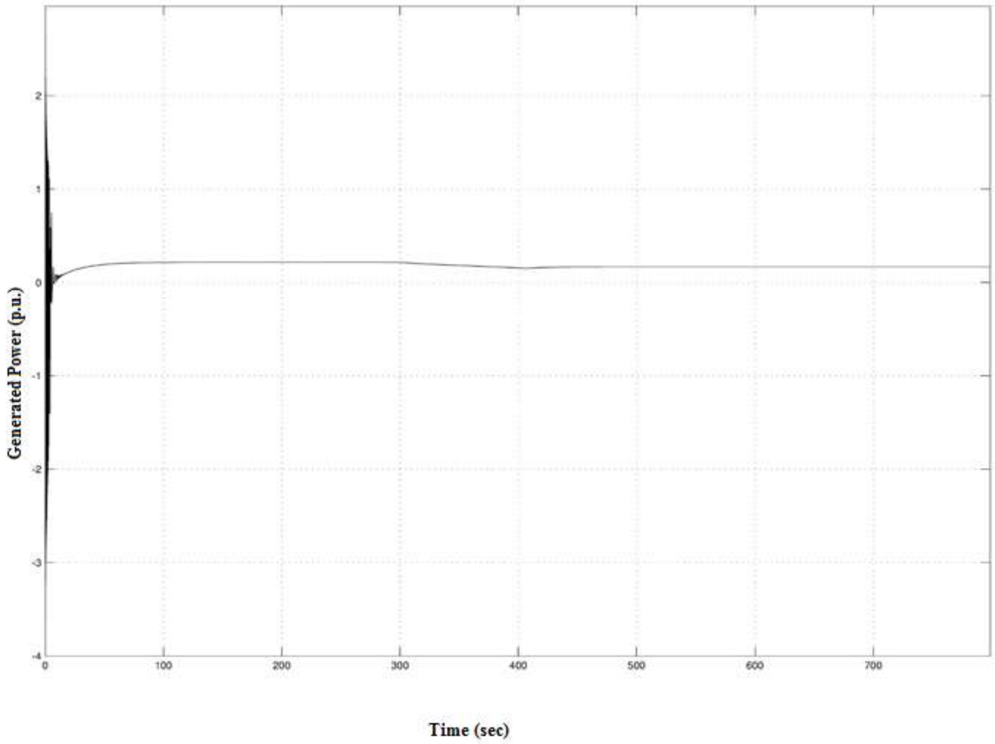

Fig 7. Variation of Generated Power with Time

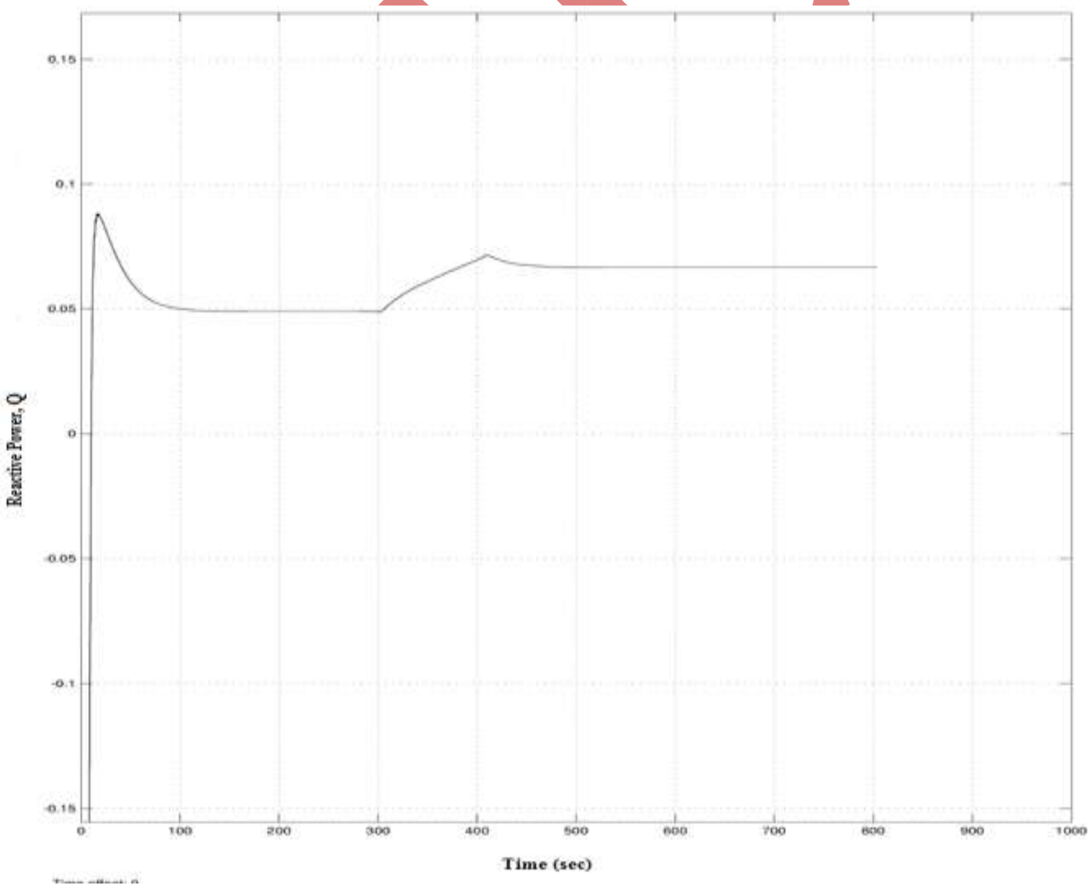

Fig 8. Variation of Reactive Power with Time

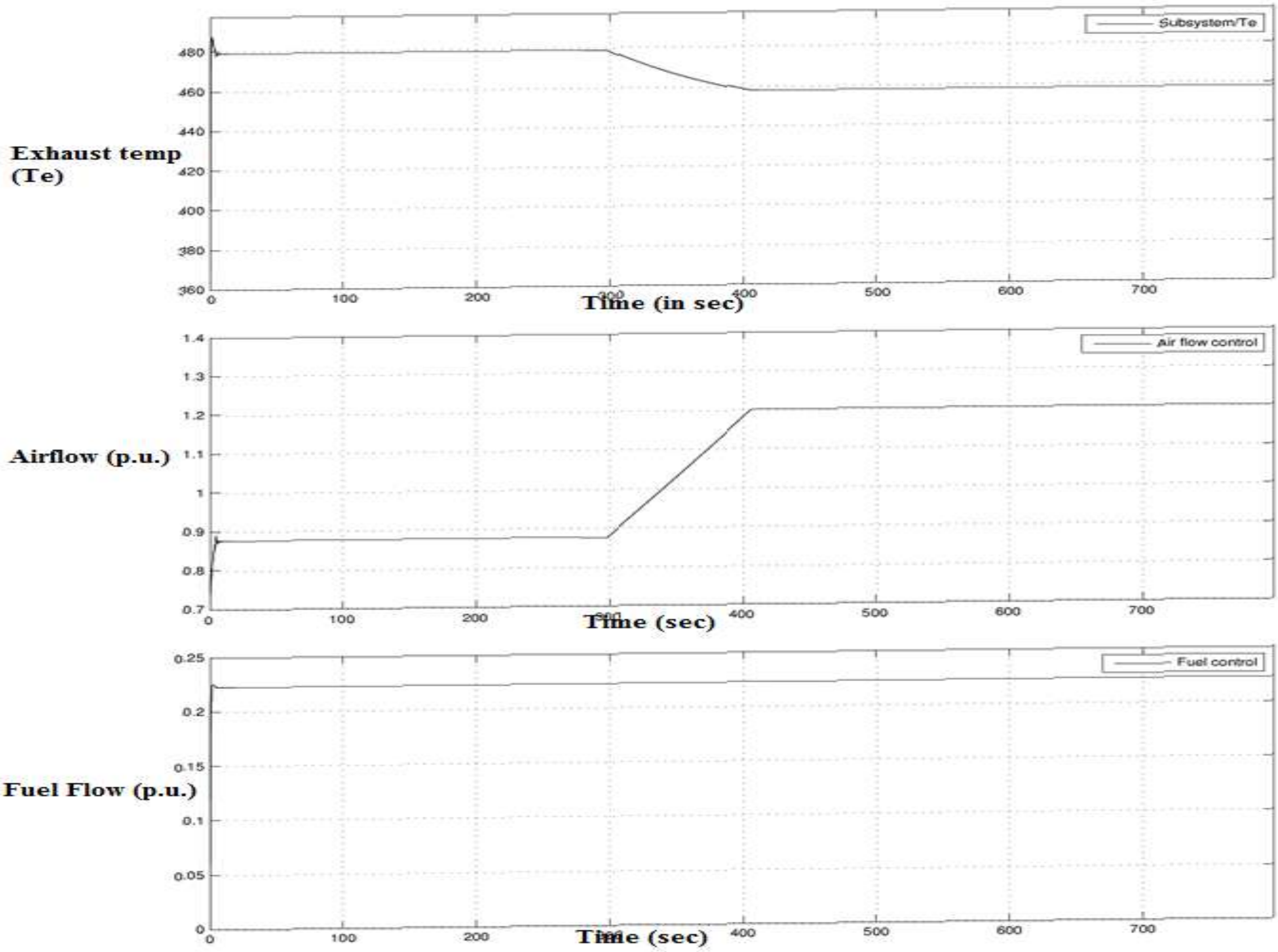

Fig 9. Variation of various System parameters with time

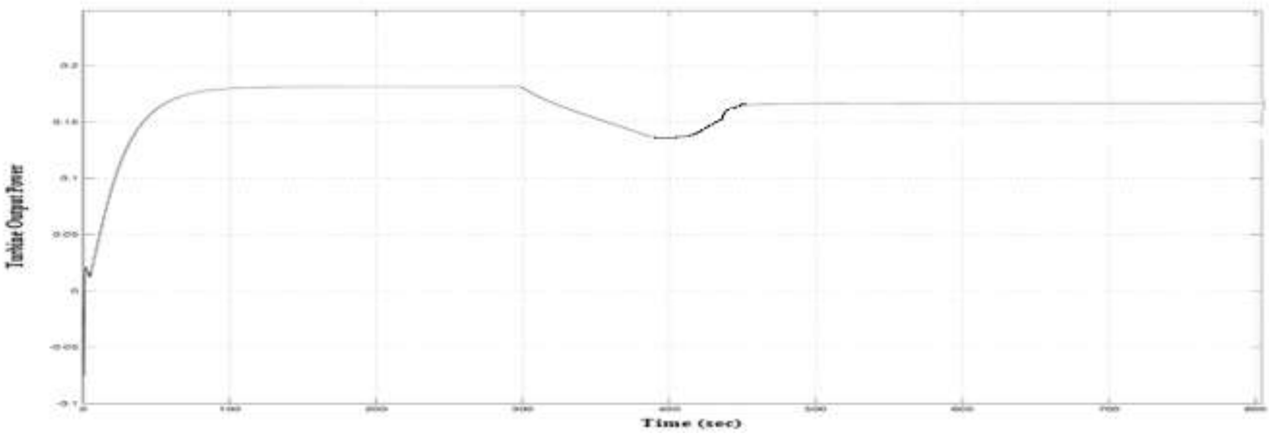

Fig 10. Variation of Turbine Output Power with Time

REFERENCES

[1]N. Kakimoto, K. Baba, , "Performance of gas turbine-based plants during frequency drops," IEEE Transactions on Power Systems,vol.18, pp. 1110- 1115, Aug. 2003.

[2]S. Al-Zubaidy, F.S. Bhinder, "Towards optimizing the efficiency of electrical power generation," Energy Conversion Engineering Conference, vol.3, pp. 1857-1862, Aug. 1996.

[3]K. Kunitomi, A. Kurita, H. Okamoto, Y. Tada, S. Ihara, P. Pourbeik, W. W. Price, A. B. Leirbukt, and J. J. Sanchez-Gasca, "Modeling frequency dependency of gas turbine output," Proc. IEEE/Power Eng. Soc. Winter Meeting, Jan. 2001.

[4]W. I. Rowen, "Simplified mathematical representations of heavy-duty gas turbines," Trans. Amer. Soc. Mech. Eng., vol. 105, pp. 865–869, Oct. 1983.

[5]F. P. de Mello and D. J. Ahner, "Dynamic models for combined cycle plants in power system studies," IEEE Trans. Power Syst., vol. 9, pp. 1698–1708, Aug. 1994.

[6]John H Horlock, "Advanced gas turbine cycles," Pergamon Press, 2003.

[7]Rolf Kehlhofer, Rukes Bert, Hannemann Frank, and Stirnimann Franz. "Combined-cycle gas & steam turbine power plants," PennWell, 2009.

[8]F. Drbal Lawrence, G. Boston Patricia, L. Westra Kayla, Black& Veatch. Power Plant Engineering. p. 241 Springer. 1996.

[9]Rai, J. N., Hasan, N., Arora, B. B., Garai, R., Gupta, R. K., & Kapoor, R. (2013). "Study the Effect of Temperature Control on the Performance of the Output of Combined Cycle Gas Turbine". International Journal of Theoretical and Applied Mechanics, 8(1), 15-23.

[10]J. N. Rai, NaimulHasan, B. B. Arora, Rajesh Garai, Rahul Kapoor, Ibraheem(2013) "Performance Analysis of CCGT Power Plant using MATLAB/Simulink Based Simulation" International Journal of Advancements in Research & Technology, Vol. 2(5), pp. 285-290

[11]Mantzaris, J., &Vournas, C. (2007). Modelling and Stability of a Single-Shaft Combined Cycle Power Plant. International Journal of Thermodynamics, 10(2).

[12]Patel, H., & Agarwal, V. (2008). MATLAB-based modeling to study the effects of partial shading on PV array characteristics. Energy Conversion, IEEE Transactions on, 23(1), 302-310.

[13]González-Longatt, F. M. (2005). Model of photovoltaic module in Matlab. II CIBELEC, 2005, 1-5.

[14]Tsai, H. L., Tu, C. S., & Su, Y. J. (2008, October). Development of generalized photovoltaic model using MATLAB/SIMULINK. In Proceedings of the world congress on Engineering and computer science (Vol. 2008, pp. 1-6).

[15]Rahim, N. A., Saidur, R., Solangi, K. H., Othman, M., & Amin, N. (2012). Survey of grid-connected photovoltaic inverters and related systems. Clean Technologies and Environmental Policy, 14(4), 521-533.

IJEEE